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ADP013968

TITLE: Electrodynamic Model of the Receiving Antenna in Terms of a Waveguide Representation of the HF Field

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TITLE: 2002 International Conference on Mathematical Methods in Electromagnetic Theory [MMET 02]. Volume 2

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ADP013889 thru ADP013989

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ELECTRODYNAMIC MODEL OF THE RECEIVING ANTENNA IN TERMS OF A WAVEGUIDE REPRESENTATION OF THE HF FIELD

Vitaly V. Khakhinov

Institute of Solar-Terrestrial Physics SD RAS
Russia, 664033, Irkutsk, P.O.Box 4026
E-mail: khakhin@iszf.irk.ru

ABSTRACT

This paper is concerned with the problem of the current excitation in the receiving antenna in the HF field. The solution of the problem is performed in terms of a waveguide representation of the HF field in the spherical Earth-ionosphere waveguide. Structurally, the antenna is treated in the form of a conductor of a finite length and arbitrary configuration.

INTRODUCTION

A variety of research problems require creating a structural physical model of the radio channel. By a radio channel is meant here the portion of the communication link in which the information signal acquires a spatial distribution. The structure of the HF radio channel consists of receive-transmit antenna-feeder systems and the Earth-ionosphere waveguide. The receiving antenna is an important element of the radio channel that requires an electrodynamic approach in a mathematical simulation. The researchers' attention to receiving antennas is inversely proportional to the factor by which their number exceeds the number of radiating antennas.

FORMULATION OF THE PROBLEM

The electrodynamic model of the receiving antenna is determined by the representation of the incident electromagnetic field. The representation of the field, in turn, is determined by the method of solving the electrodynamic problem for radio wave propagation. The model was constructed in terms of a waveguide representation of the HF field in the spherically symmetric Earth-ionosphere waveguide. It was assumed that the receiving antenna does not disturb the structure of the incident field. Use was made of the geocentric coordinate system with the polar axis passing through the phase center of the radiating element (the radius-vector is $\mathbf{r}_s = (r_s, 0, \varphi_s)$). The field was calculated on the basis of the method of normal waves [1-3].

The antenna is regarded as a conductor of finite length with an arbitrary configuration, and when treated electrostatically, it represents a long uniform line with the distributed (along it) electromotive force (EMF). Current is excited by the electric field component E_r along the conductor axis. In calculations, E_r is taken at points infinitely close to the conductor surface.

In the spherically symmetric waveguide the incident electromagnetic field breaks into the field of TM waves (with the symbol "e") containing the E_r and E_θ components of the electric field, and the field of type TE waves (with the symbol "m") containing the E_φ

component. An expression for EMF induced at the element dl of the antenna may be written as:

$$d\varepsilon = d\varepsilon^e + d\varepsilon^m = [(\mathbf{e}_r \mathbf{e}_l) E_r(\mathbf{r}_l) + (\mathbf{e}_\theta \mathbf{e}_l) E_\theta(\mathbf{r}_l)] dl + (\mathbf{e}_\varphi \mathbf{e}_l) E_\varphi(\mathbf{r}_l) dl. \quad (1)$$

Here \mathbf{e}_r , \mathbf{e}_θ and \mathbf{e}_φ are unit vectors of the coordinate system; $\mathbf{r}_l = (r_l, \theta_l, \varphi_l)$ is the radius-vector of the antenna element; and \mathbf{e}_l is the unit vector along dl . In the general case the expression for the j component of the field is a series for normal waves:

$$E_j(\mathbf{r}_l) = \frac{1}{r_l} \sum_n A_n R_n(r_l) D_{jn}(\mathbf{I}, \varphi) e^{i(v_n \theta_l - \pi/4)} \quad (2)$$

Here A_n is the amplitude factor; D_{jn} stands for the coefficients of excitation of normal waves by the radiator with a given distribution of current \mathbf{I} which characterize the distribution of radiated energy in normal waves; and R_n and v_n are the eigenfunctions and the eigenvalues of the respective boundary-value problems for TM and TE waves.

COEFFICIENTS OF RECEPTION OF NORMAL WAVES

The induced EMF generates two running current waves: from dl to the receiving end of the antenna and to the end of the antenna with load resistance Z_R . At the ends of the antenna the waves are partially reflected and partially absorbed in load resistance or escape via the feeder line to the receiver. To calculate the current we used the method of superposition of running waves [4]. By summing all components of the running and reflected waves, it is possible (according to [4](p.189)) to obtain the expression for the current at an arbitrary point of the antenna. The value of the current at the receiving end of the antenna may be written as:

$$dJ_0 = \frac{Y(l)}{W} d\varepsilon \quad (3)$$

Here: $Y(l) = \frac{e^{ikl} + p_F e^{ikl} + p_R e^{ik(2L-l)} + p_F p_R e^{ik(2L-l)}}{2(1 - p_F p_R e^{i2kl})}$; W is the wave resistance of the

conductor; L is the antenna length; $p_F = (W - Z_F)/(W + Z_F)$ and $p_R = (W - Z_R)/(W + Z_R)$ are the coefficients of reflection of current from the ends of the antenna; and Z_F is the input resistance of the feeder line loaded by the receiving device. The function $Y(l)$ defines the distribution of current in the antenna with regard for the load conditions at both ends. Substitute (1) into (3) by using the expressions (2) for the components of the field. The value of total output current is determined by integrating along the length of the receiving antenna:

$$J_0 = \sum_n A_n \left(D_n^c P_n^c e^{i v_n^c \theta_l} + D_n^m P_n^m e^{i v_n^m \theta_l} \right) \quad (4)$$

The integration used the condition of the smallness of the antenna's linear size compared with the distance to the radiator. The functions:

$$P_n^c = \int_l \frac{Y(l)}{W r_l} \left[(\mathbf{e}_r \mathbf{e}_l) \frac{v_n}{k r_l} R_n^c(r_l) - (\mathbf{e}_\theta \mathbf{e}_l) \frac{dR_n^c(r_l)}{i k \varepsilon' dr} \right] e^{-i v_n^c \theta_l \cos(\varphi_s - \varphi_l)} dl \quad (5)$$

$$P_n^m = \int_l (\mathbf{e}_\varphi \mathbf{e}_l) \frac{Y(l)}{W r_l} R_n^m(r_l) e^{-i v_n^m \theta_l \cos(\varphi_s - \varphi_l)} dl$$

constitute the essence of the electrodynamic model of the receiving antenna in terms of a waveguide representation of the exciting HF field. They characterise the level of induced current by the components of the TM and TE field of a separate normal wave and are determined by the parameters of the receiving antenna. It is therefore logical to call $P_n^{e,m}$ the coefficients of reception of normal waves of corresponding polarisation.

RECEIVING ANTENNA EFFECTIVE LENGTH

A key characteristic of the receiving antenna is believed to be the effective length defined as the ratio of the current strength at the receiving end to the value of the incident field strength at the phase center of the antenna. It is natural to select, as the phase center of the antenna, its receiving end with the radius-vector \mathbf{r}_F . If the expression for $Y(l)$ is transformed to the form [4](p.194): $Y(l) = \tilde{Y}(l)/(Z + Z_F)$, (here Z is the input resistance of the antenna with Z_R taken into account), then the expression for output current may be written in terms of the antenna effective length:

$$J_0 = \frac{E(\mathbf{r}_F)h_d}{Z_a + Z_F}, \quad (6)$$

by defining the expression for h_d as:

$$h_d = \frac{1}{E(\mathbf{r}_F)} \sum A_n \left(D_n^e \tilde{P}_n^e e^{iv_n^e \theta_s} + D_n^m \tilde{P}_n^m e^{iv_n^m \theta_s} \right), \quad (7)$$

where \tilde{P}_n^e and \tilde{P}_n^m are determined by formulas (5) with the replacement of $Y(l)$ by $\tilde{Y}(l)$.

CONCLUSIONS

The electrodynamic model that has been constructed here for the receiving antenna in terms of the method of normal waves is represented by the coefficients P_n^e and P_n^m . They represent the influence of the characteristics of the receiving antenna and, primarily, its directed properties, when the energy of the incident TE and TM waves of the field transforms to the energy of current oscillations.

ACKNOWLEDGEMENTS

This work was done with support from the Russian foundation for Basic Research grant for leading scientific schools of the Russian Federation No.00-15-98509.

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